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Accuracy of treatment planning calculations for conformal radiotherapy

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Chapter X

Discussion and conclusions

X. Discussion and conclusions

Knowledge about treatment planning accuracy is shown in the introductory section of this thesis to be a crucial requirement for the enhancement of treatment planning capabilities, and thus an essential condition to achieve the expected benefits of conformal radiotherapy.

In this thesis research has been performed to define the accuracy of dose and volume calculations that are essential for conformal radiotherapy treatment planning. This concerns especially the region where highest benefits are to be expected: the edges and shielded parts of the beams.

In Chapter III dose distributions calculated with pencil beam kernels in blocked fields without a wedge have been verified and found to be correct mostly within ± 3 [%;mm]. This study defines the dosimetric basis of the first achievement, in historical perspective, of conformal treatment: an improved confinement of the treated volume to the PTV by the application of individual shielding blocks designed in Beam's-Eye-View. It has been documented that considerable errors can be found in blocked field calculations in current treatment planning systems.¹ However, Chapter III shows that the investigated pencil beam model has an associated dose calculation accuracy in these cases that falls well within accepted accuracy criteria of $\pm 3\%$ or 3 mm. In subsequent versions of the treatment planning system the beam model has been further generalized, allowing broader applications to be calculated with high accuracy,^{2,3} however, at the expense of somewhat less accuracy in 'classical' situations. This development and distinct energies explain the difference between the Fig. 3a in Chapter III and Fig. 2c in Chapter I.

In Chapter IV a lung tumour geometry has been studied by phantom measurements, one of the most challenging geometries in treatment planning. Large discrepancies, up to 21% in megavoltage photon dose, between current pencil beam calculations and measurements were found. The pencil beam model clearly does not properly take into account the increased penumbra width in low density material and thus yields possibly a too low dose in, for example, the PTV of a lung tumour. The classical approach to compensate for this effect is to increase margins in lung tumour treatment, at the expense of unwanted normal tissue dose.⁴ This drawback is minimized in another approach, in which the beam size is reduced by compensation of the penumbra.^{5,6} However, in the lack of sufficient accuracy in current algorithms, the amount of compensation is usually based on general, and thus approximate rules that have been derived for a limited set of geometries. In Chapter II the same lung tumour geometry has been used to verify calculations with a point spread kernel algorithm. This algorithm produces much better results, mostly within $\pm 2\%$ dose accuracy. This accuracy allows more accurate, individual penumbra compensation in lung tumour geometries to be based directly on treatment planning calculations.

In Chapters V and VI methods have been developed for high-resolution measurements of beam edges with current ionization chambers, thus in particular suited for routine verification measurements. By correction for the spatial response of such an ionization chamber with the derived line spread functions, an improvement of up to 2 mm in accuracy in the description of megavoltage photon penumbras (20%-80%) is achieved. This is approximately 1 mm better than a correction function based on detector geometry⁷ achieves. Note that 1 mm artificial penumbra broadening corresponds to an increase in volume of 12% of a 25 mm radius sphere, representing, for instance, a planning target volume. The correction functions derived in Chapters V and VI are currently applied on a routine basis for verification measurements of treatment planning calculations.

In Chapter VII a 2D detector, consisting of a scintillating screen and a CCD camera has been verified for dosimetry purposes in proton beams. A line spread function was found to be described by a Gaussian distribution with a standard deviation of 0.22 mm. This detector has been applied to verify results of a Monte Carlo study into the contribution of collimator scatter to the dose in small proton beams. Scatter on air is found to be the major contribution to the extent of the penumbra. Nevertheless, very sharp penumbras (20%-80%) of 0.5 mm and less could be created, allowing a dose deposition that is very sharply confined to the target volume.

In Chapter VIII the accuracy of grid-based volume sampling has been shown to be dependent on the shape of the sampled structure. For a typical prostate, with volume 77 cm³, 1050 grid points were required to obtain a 1% relative uncertainty in the sampled volume, corresponding to a 4 mm grid size. Note that in the treatment planning systems that is used at our hospital (Helax-TMS), volumes are sampled on a plane-by-plane basis in the dose calculation planes, whereas separate grids for volume and dose volume histogram sampling are used. In that case the results of area sampling, also described in Chapter VIII, should be applied. Note furthermore that dose surface histograms and dose wall histogram have recently been promoted^{8,9} to sample hollow organs as bladder and rectum. The obvious advantage of these techniques is that a more evenly distributed set of sampling points can be obtained, thus necessitating less points for the same accuracy. However, the data on rectum wall sampling in Chapter VIII indicate that 1% and 5% relative uncertainty in the sampled wall volumes require cubic grid sizes of approximately 2 mm and 4 mm, respectively, values that comply with the normal usage of a treatment planning system.

With these fundamental issues in treatment planning accuracy defined, a comprehensive procedure has been developed for the verification of treatment planning calculation accuracy, and for the presentation of systematic dose calculation errors during treatment planning. Important elements in this procedure are the concepts of combinatorial verification and field accuracy. Combinatorial verification aims at discovering all possible ‘dust traps’ that might be hidden in ‘verification space’. The multitude of field parameter combinations that has to be explored, is handled via the implementation of a profile database and a comparison facility. The field accuracy concept aims at simultaneous verification of dose and positional accuracy criteria. A survey of available literature lead to the conclusion that accuracy criteria for treatment planning calculations would ideally be 2% or 2 mm, whereas 3% or 3 mm is often seen as presently acceptable. The field accuracy concept has proven to be a valuable assessment tool to check compliance to these criteria.

A new, extended application of this combinatorial verification is the presentation of discrepancy estimates for entire treatment plans. The feasibility of this application has been investigated in the case of a conformal prostate treatment plan. The results obtained in this case have proven the possibility of a comprehensive presentation, in a clinically easily appreciable way, of an estimated distribution of discrepancies in an entire treatment plan, based on verified treatment planning accuracies.

Summarizing, this thesis provides the knowledge that was required to define and improve the accuracy of treatment planning calculations for conformal radiotherapy. Furthermore, a verification programme has been designed to explore the combined influence of beam parameters on calculation accuracy, commonly encountered in clinical treatment plans. Finally, the feasibility has been confirmed of the presentation of the calculation accuracy in individual treatment plans.

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